



## Equipment and Placement Techniques for Subaqueous Capping

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**PURPOSE:** Dredged material and in situ sediments may contain contaminants at sufficient concentrations to degrade the benthic environment. In cases where unacceptable toxicity or bioaccumulation is predicted to occur, subaqueous capping with a layer of clean material is often an acceptable management or remediation alternative.

This technical note (TN) describes equipment and placement techniques for subaqueous capping projects. The equipment and techniques are applicable to placement of contaminated material to be capped and clean material to be used for capping and include conventional discharge from barges, hopper dredges, and pipelines; submerged discharge from diffusers and tremies; and surface spreading techniques for cap placement. Both granular capping materials such as sediments and soils and geosynthetic fabrics and armoring materials are considered.

**BACKGROUND:** Detailed guidance on engineering considerations for dredged material capping and in situ sediment capping can be found in Palermo et al. (1998a, 1998b). These guidance documents include information on equipment and placement techniques used in projects up to about 1994. The information in this TN is intended to supplement and update the existing guidance on equipment and placement techniques by including descriptions of equipment types and techniques successfully used from 1994 to 2004. For completeness, this TN also includes information on equipment and placement techniques taken from the earlier capping guidance documents.

A variety of equipment types and placement techniques have been used for capping projects. Conceptual illustrations of capping equipment are shown in Figure 1.

Capping is the controlled, accurate placement of clean isolating material to cover or cap contaminated material at a sediment site or an open-water disposal site. For purposes of this TN, the term “contaminated” refers to material found to be unacceptable for unrestricted open-water disposal because of potential contaminant effects, while the term “clean” refers to material found to be acceptable for such disposal.

Level-bottom capping (LBC) may be defined as the covering of a mound of contaminated material with clean material following placement of the dredged material on the bottom in a mounded configuration. Contained aquatic disposal (CAD) is similar to LBC but with the additional provision for some form of lateral confinement (for example, placement in bottom depressions or behind subaqueous berms) to minimize spread of the materials on the bottom. In situ capping (ISC) refers to placement of a cap over an in situ deposit of contaminated sediment. A variation on ISC could involve the removal of contaminated sediments to some depth, followed by capping the remaining sediments in place (Palermo et al. 1998b). CAD and LBC are illustrated in Figure 2.

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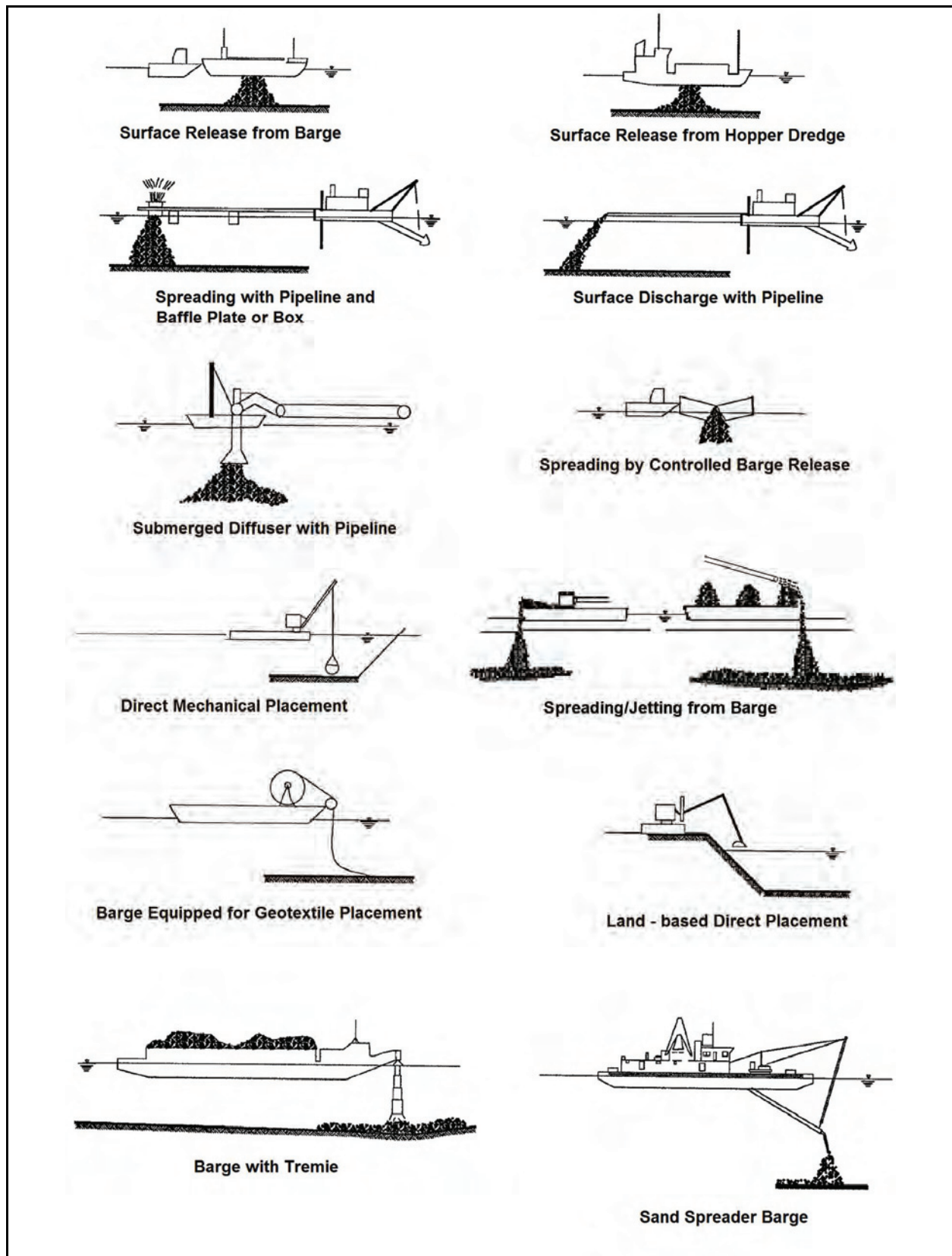


Figure 1. Conceptual illustrations of equipment that can be considered for capping

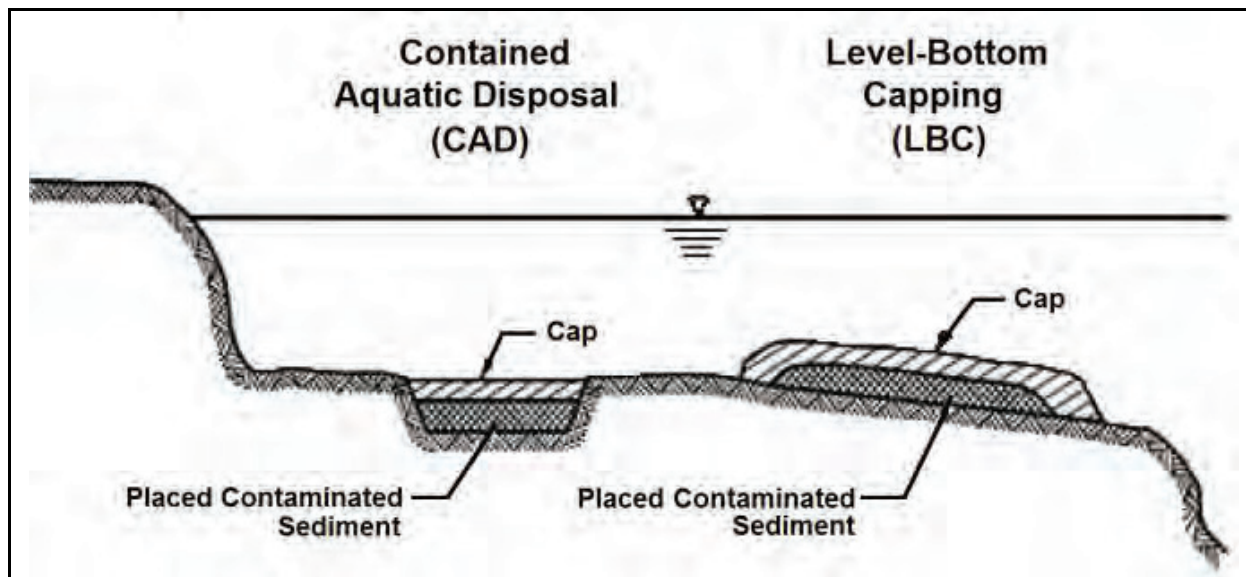


Figure 2. Conceptual illustration of dredged material capping options

**DESIGN REQUIREMENTS FOR CAPPING:** Using appropriate equipment and placement techniques for both contaminated material and capping material is critical to any capping operation. However, all components of design for a capping project are strongly interdependent. The major design requirements for a capping project and the sequence in which the design requirements should be considered are fully described in *Dredging Research Technical Note* (TN) DRP-5-03 (Palermo 1991) or the two capping guidance documents: “Guidance for Subaqueous Dredged Material Capping” (Palermo et al. 1998a) and “Guidance for In-Situ Subaqueous Capping of Contaminated Sediments” (Palermo et al. 1998b). Equipment and placement techniques for a specific project should be selected within the context of the overall design requirements for the project as described in the guidance documents.

A number of important placement considerations are also described in detail in the guidance documents, but are omitted here. These include:

- Geotechnical compatibility.
- Navigation and positioning requirements.
- Inspection and compliance.
- Exposure time between contaminated material and cap placement.

The guidance documents also include a section describing the restrictions and tolerances associated with each placement technique (stationary placement, use of multiple disposal points or lanes, and spreading over large areas).

**CONSIDERATIONS FOR CAPPING MATERIAL PLACEMENT:** For granular cap components, the major consideration in selecting equipment and placement of the cap is the need for controlled, accurate placement and the resulting density and rate of application of capping material. In general, the cap material should be placed so that it accumulates in a layer covering the contaminated material. Using equipment or placement rates that might result in the capping

material displacing or mixing with the contaminated material should be avoided. Sand caps have been successfully placed over fine-grained contaminated material with minimal mixing of the cap with the contaminated sediment (Mansky 1984; Bokuniewicz 1989; Bruin et al. 1985; Zeman and Patterson 1996a, 1996b). Since the surface area to be capped may be several hundred feet or more in diameter, placement of a cap of required thickness over such an area may require placement techniques to spread the material to some degree to achieve coverage.

Site considerations that can influence equipment selection include water depths and wave/current conditions. Other site conditions such as bottom topography, other vessel traffic, thermal/salinity stratification of the water columns (for deepwater sites), etc. may also have an influence. Pipeline and barge placement of dredged material for ISC projects is appropriate in more open areas such as harbors or wide rivers. In constricted areas, narrow channels, or shallow nearshore areas, conventional land-based construction equipment may also be considered.

Potential resuspension of the contaminated material by impact of capping material should be considered in selecting the equipment and placement technique for the cap. No standardized method is presently available to calculate the potential resuspension of sediment and associated contaminant release due to such resuspension. Monitoring at capping sites has generally focused on cap thickness and coverage rather than sediment resuspension. At an ISC demonstration in Hamilton Harbor, Environment Canada monitored the water column and tracked a small plume of suspended material. Analysis of the material in suspension indicated that it was predominantly fines that had been washed off the sand capping material during placement and not resuspended contaminated sediments (Zeman and Patterson 1996a, 1996b).

Since capping materials are not contaminated, water column dispersion of capping material is not usually of concern (except for loss of fine-grained cap materials or when slowly placing a sand cap); the use of submerged discharge for capping placement need only be considered from the standpoint of control during placement.

#### **EQUIPMENT AND PLACEMENT TECHNIQUES FOR GRANULAR CAP MATERIALS:**

Granular cap material can be handled and placed in a number of ways. Materials that have been mechanically dredged and soils excavated from an upland site or quarry have relatively little free water; they can be handled mechanically in a "dry" state until released into the water over the contaminated site. These mechanical methods rely on the gravity settling of cap materials in the water column and may be depth-limited in their application. Granular cap materials can also be entrained in a water slurry and carried to the cap site, where they are discharged into the water column at the surface or at depth. These hydraulic methods offer the potential for a more precise placement, although the energy required for slurry transport may require dissipation to prevent resuspension of contaminated sediments.

**Direct Mechanical Placement.** If the area to be capped is nearshore and appropriate access is available, direct mechanical placement of capping material with land-based equipment can be considered. The reach of the equipment is the major limitation. Since the capping material would likely be trucked to the site with this method, access for the trucks and traffic should be considered. Land-based methods might include backhoes, clamshells, end-dumping from trucks,

spreading with dozers (during low-water periods), etc. A cap with layers of gravel and geotextile was placed using land-based equipment (Figure 3) at a site on the Sheboygan River (Eleder 1992). At the GM Superfund site in Massena, New York, sand and gravel cap materials were placed in the St. Lawrence River with a backhoe bucket from a work barge.<sup>1</sup>



Figure 3. Land-based cap placement at Sheboygan River

At the Pine Street Canal Superfund Site, the site was temporarily dewatered to install the cap in the “dry” using conventional construction equipment. This allowed easier placement of the geotextile/geogrid, as well as allowing the sediment to gain strength such that thicker sand lifts could be placed with Bobcat equipment (Maynard and Crandall 2003).

**Surface Discharge Using Conventional Dredging Equipment.** Dredged material released at the water's surface using conventional equipment tends to descend rapidly to the bottom as a dense jet with minimal short-term losses to the overlying water column (Bokuniewicz et al. 1978, Truitt 1986). Thus, the use of conventional equipment can be considered for placement of both contaminated and capping material if the bottom spread and water column dispersion resulting from such a discharge are acceptable.

The surface release of mechanically dredged material from barges results in a faster descent, tighter mound, and less water column dispersion as compared to surface discharge of hydraulically dredged material from a pipeline. Surface release of hydraulically dredged material from a hopper dredge results in placement characteristics that fall between the characteristics for surface release of hydraulically dredged material from barges and surface discharge of hydraulically dredged material from a pipeline. Therefore, the descent is slower than the former but faster than the latter; the mound is looser than the former but tighter than the latter; and water column dispersion is greater for the former than for the latter.

Field experiences with LBC operations in Long Island Sound and the New York Bight have shown that mechanically dredged silt and clay released from barges tend to remain in clumps during descent and form nonflowing discrete mounds on the bottom, which can be effectively capped. Such mounds have been capped with both mechanically dredged material released from

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<sup>1</sup> Personal Communication. 1997. Mr. E. Thomas Kenna, Environmental Engineer, U.S. Army Engineer District, Buffalo, Buffalo, NY.

barges and with material released from hopper dredges (O'Connor and O'Connor 1983; Morton 1983, 1987). In fact, mechanically dredged cohesive sediments often remain in a clumped condition, reflecting the shape of the dredge bucket. Mounds of such material are very stable, resist displacement during capping operations, and present conditions ideal for subsequent LBC (Sanderson and McKnight 1986). However, these mounds may experience initial surface erosion due to irregular surface geometry and higher friction coefficients. Figure 4 is a conceptual illustration showing the use of conventional equipment for capping.

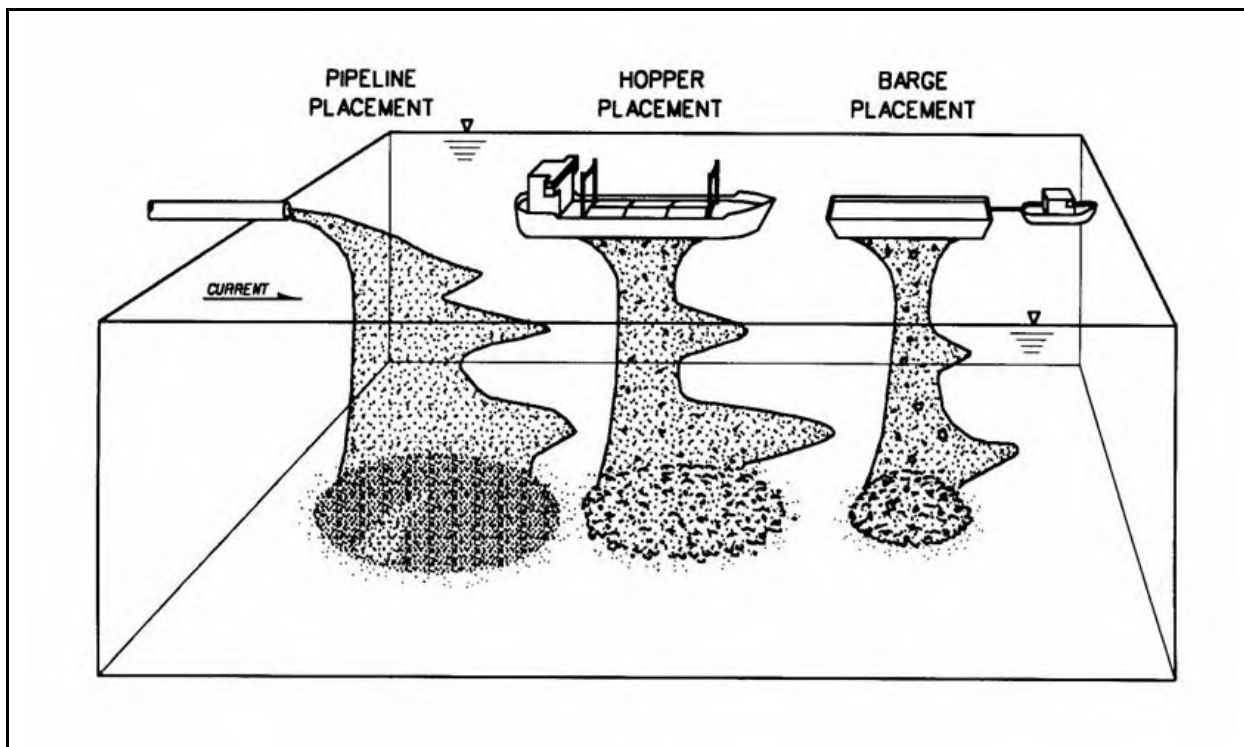


Figure 4. Conventional open-water placement for capping

Surface discharge of material from barges or hopper dredges would not normally be considered for in situ capping unless special provisions were made for gradual release of the material and spreading it over a larger area. Point discharges from hopper dredges or barges would normally not be applicable for in situ capping of soft fine-grained contaminated sediments.

At the Ward Cove sediment remediation project in Ketchikan, Alaska, a barge-mounted clamshell bucket (Figure 5), modified with baffle plates (to provide a consistent grab volume), was used to place thin lifts of sand over soft sediments (with high moisture content and low bearing strength) (Herrenkohl et al. 2003).

**Spreading by Barge Movement.** A layer of capping material can be spread or gradually built up using bottom-dump barges if provisions are made for controlled opening or movement of the barges. This can be accomplished by slowly opening a conventional split-hull barge over a 30- to 60-min interval, depending on the size of the barge and site conditions. Such techniques have been successfully used for controlled placement of predominantly coarse-grained, sandy



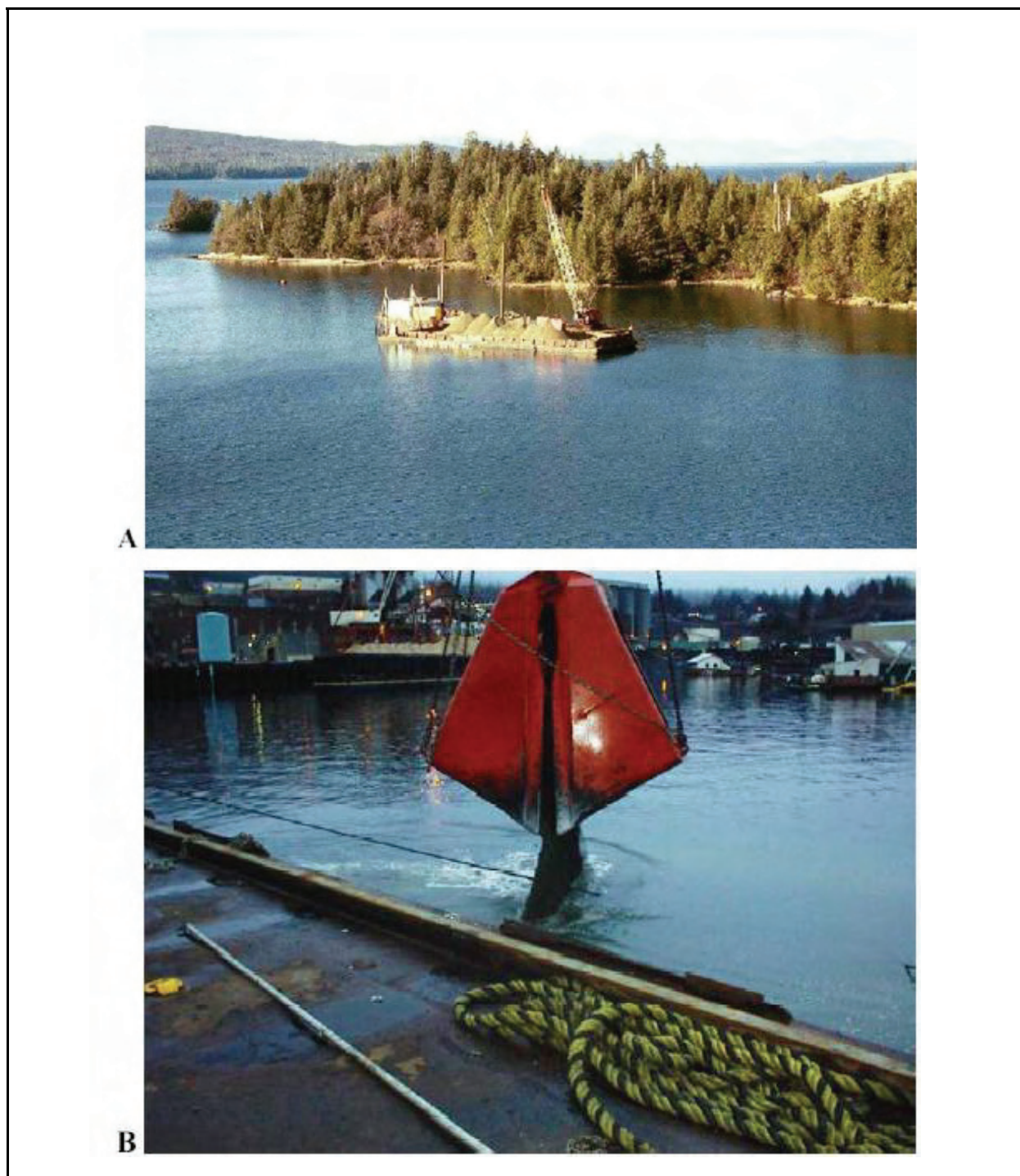


Figure 5. 8.5-yd<sup>3</sup> bucket used to release cap material underwater in a 300-ft arc to provide 6-in. lifts at Ward Cove, Alaska

capping materials at the Denny Way and other sites in Puget Sound (Sumeri 1989, 1995). The gradual opening of the split-hull or multi-compartment barges allows the material to be released slowly from the barge in a sprinkling manner.



If two tugs are used to slowly move the barge sideways during the release, the material can be spread in a thin layer over a large area (Figure 6). Multiple barge loads are necessary to cap larger areas in an overlapping manner. The gradual release of fine-grained silts and clays mechanically loaded into barges may not be possible due to potential "bridging" action; that is, the cohesion of such materials may cause the entire bargeload to "bridge" the split-hull opening until a critical point is reached at which time the entire bargeload is released. If the water content of fine-grained material is high, as in the case of hydraulic filling of barges, the material may exit the barge in a matter of seconds as a dense slurry, even though the barge is only partially opened.



Figure 6. Spreading techniques for capping by barge movement at Denny Way, Puget Sound

Thin layers of cap material can also be spread over large areas by gradually opening a conventional split-hull barge while underway by tow. This technique has been successfully used for capping operations at Eagle Harbor, WA (Nelson et al. 1994; Sumeri 1995). Barges may not be suitable for spreading cap materials in shallow water because of the water depths needed for barge draft and door openings, and because of the propeller wash from tugboats.

**Hydraulic Washing of Coarse Sand.** Granular capping materials such as sand can be transported to a site in flat-topped barges and washed overboard with high-pressure hoses. Such an operation was used to cap a portion of the Eagle Harbor Superfund site, forming a cap layer of uniform thickness (Figure 7). This technique produces a gradual buildup of cap material, prevents any sudden discharge of a large volume of sand, and may be suitable for water depths as shallow as 10 ft or less.



Figure 7. Hydraulic washing of coarse sand, Eagle Harbor, Puget Sound

**Spreading by Hopper Dredges.** Hopper dredges can also be used to spread a sand cap. During the summer and fall of 1993, the Port Newark/Elizabeth capping project in New York Bight used hopper dredges to spread a sand cap over 580,000 yd<sup>3</sup> of contaminated sediments. To facilitate spreading the cap in a thin layer (6 in.) to quickly isolate the contaminants and to lower the potential for resuspension of the contaminated material, conventional point dumping was not done. Instead, a split-hull dredge cracked the hull open 1 ft and released its load over a 20- to 30-min period while sailing at 1-2 knots. As an alternative means of placing the cap, another dredge used pump-out over the side of the vessel through twin vertical pipes with end plates to force the slurry in the direction the vessel was traveling. As with the cracked hull method described above, injecting the slurry into the direction of travel of the vessel increased turbulence, reducing the downward velocity of the slurry particles and thus the potential for resuspension of the contaminated sediments. Computer models were used to predict the width of coverage from a single pass and the maximum thickness produced (Randall et al. 1994).

Similar to the operation above, at the Palos Verdes Shelf pilot capping project, placement operations were conducted using a split-hull hopper dredge by (1) the conventional method of releasing material at placement points, (2) spreading the material by partially opening the split hull while maintaining slow forward motion, and (3) pumpout through the hopper dragarms.



Though each method was effective, it appeared that spreading placement may result in a cap with greater uniformity.

**Pipeline with Baffle Plate or Sand Box.** Where granular cap material is excavated by a hydraulic dredge or transported in a slurry form through a pipeline, capping by spreading placement operations can be easily accomplished with a surface discharge using an energy-dissipating device such as a baffle plate or sand box attached to the end of the pipeline. Hydraulic placement is well-suited to placement of thin layers over large surface areas.

A baffle plate (Figure 8), sometimes called an impingement or momentum plate, serves two functions. First, as the pipeline discharge strikes the plate, the discharge is sprayed in a radial fashion and is allowed to fall vertically into the water column. The decrease in velocity reduces the potential of the discharge to erode material already in place. Second, the angle of the plate can be adjusted so that the momentum of the discharge exerts a force, which can be used to swing the end of the

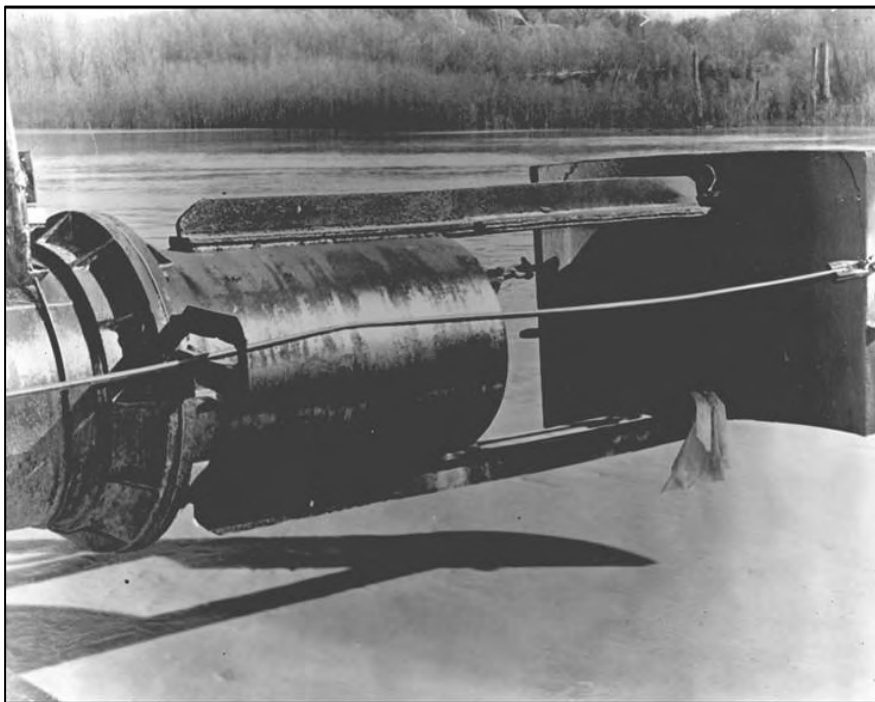


Figure 8. Baffle plate for hydraulic pipeline discharge

floating pipeline in an arc. These plates are commonly used in river dredging operations where material is deposited in thin layers in areas adjacent to the dredged channel (Elliot 1932). Such equipment can be used in capping operations to spread very thin layers of material over a large area, thereby gradually building up the required capping thickness.

A device called a "sand box" (Figure 9) serves a similar function. This device acts as a diffuser box with baffles and sideboards to dissipate the energy of the discharge. The bottom and sides of the box are constructed as an open grid or with a pattern of holes so that the discharge is released through the entire box. The sand box was used to successfully apply a sand cap at the Simpson Kraft Tacoma site in Puget Sound (Sumeri 1989).



Figure 9. Spreader box or sand box for hydraulic pipeline discharge, Simpson Kraft Tacoma, Puget Sound

Pumping sand through a moving perforated pipe system has also been used to spread thin layers of sand over soft clay slurries in Singapore (Tan et al. 2003).

**Sprayed Slurry.** At Mock's Pond in Muncie, Indiana, a sprayer assembly or "sand cannon" was used to place sand in shallow areas. The sand was slurried, then projected aerially out to the placement area over geotextile with a nozzle attached to the bucket of a track hoe (Thompson et al. 2003a). A sprayed slurry system (Figure 10) was also used at Soda Lake, Wyoming, to construct a sand cap in shallow areas using successive 1.5- to 3-in. lifts (Thompson et al. 2003b).

**Spreader Barges.** An automated hydraulic capping barge (Figure 11) has been developed in The Netherlands for the placement of thin layers of sand for capping of contaminated sediments or as a foundation layer on very soft sediments. The system was developed by the Dutch dredging firm, Royal Boskalis Westminster, in alliance with Bean Environmental LLC, of New Orleans, Louisiana. The system consists of a spreader barge connected to a slurry pump, which is loaded by either a dredge or hopper. The production of the solids is measured real-time. The winch system of the capping barge is a fully automated, dynamic tracking system and follows parallel lanes. The hauling speed of the barge is automatically steered by the quantity of capping material discharged, the lane width, and the required layer thickness of the cap. The system was used in the construction of foundation layers at the Derde Merwede Haven and Ketelmeer confined disposal facilities and for the placement of foundation layers at the Ijburg residential island construction in Amsterdam, where very thin layers of sand were required to be placed on an extremely soft surface sediment. All of these sites are located in The Netherlands. The



Figure 10. Sprayed slurry system placing sand at Soda Lake, Wyoming



Figure 11. Automated hydraulic capping barge



automated capping barge achieves production rates in excess of 1500 m<sup>3</sup>/hr and provides material distribution of clean, poorly graded imported sand in uniform 0.3-m to 0.7-m layer thickness by means of this sophisticated slurry control and barge advance system. This hydraulic capping system is available in larger or smaller scale versions.

Another spreader barge used in the United States at Mock's Pond, Muncie, Indiana, and Soda Lake, Wyoming, (Figure 12) consists of two centrifugal pumps mounted on a barge with an 8-in. slurry line and 16-ft-wide diffuser plate (Thompson et al. 2003a, 2003b). A sand slurry was pumped to the spreader barge where it was distributed laterally less than 1 ft above the water column, providing 1.5- to 3-in. lifts. Movement of the spreader barge was controlled by a cable fixed to two pendant lines and a winch mounted on the barge. The equipment is capable of placing sand in veneer lifts to avoid displacement and mixing of soft layers.



Figure 12. Spreader barge at Mock's Pond, Indiana

**Submerged Discharge.** If the placement of the contaminated sediment with surface discharge results in unacceptable water column impacts or if the anticipated degree of spreading and water column dispersion for either the contaminated or capping material is unacceptable, submerged discharge is a potential control measure.

In the case of contaminated dredged material, submerged discharge serves to isolate the material from the water column during at least part of its descent. This isolation can minimize potential chemical releases due to water column dispersion and significantly reduce entrainment of site water, thereby reducing bottom spread and the area and volume to be capped. In the case of capping material, the use of submerged discharge provides additional control and accuracy during placement, thereby potentially reducing the volume of capping material required. Several equipment alternatives available for submerged discharge (Palermo 1994b) are described in the following paragraphs.

**Submerged Diffuser.** A submerged diffuser (Figures 13 and 14) can be used to provide additional control for submerged pipeline discharge (Neal et al. 1978; Palermo 1994b). The diffuser consists of conical and radial sections joined to form the diffuser assembly, which is mounted to the end of the discharge pipeline. A small discharge barge is required to position

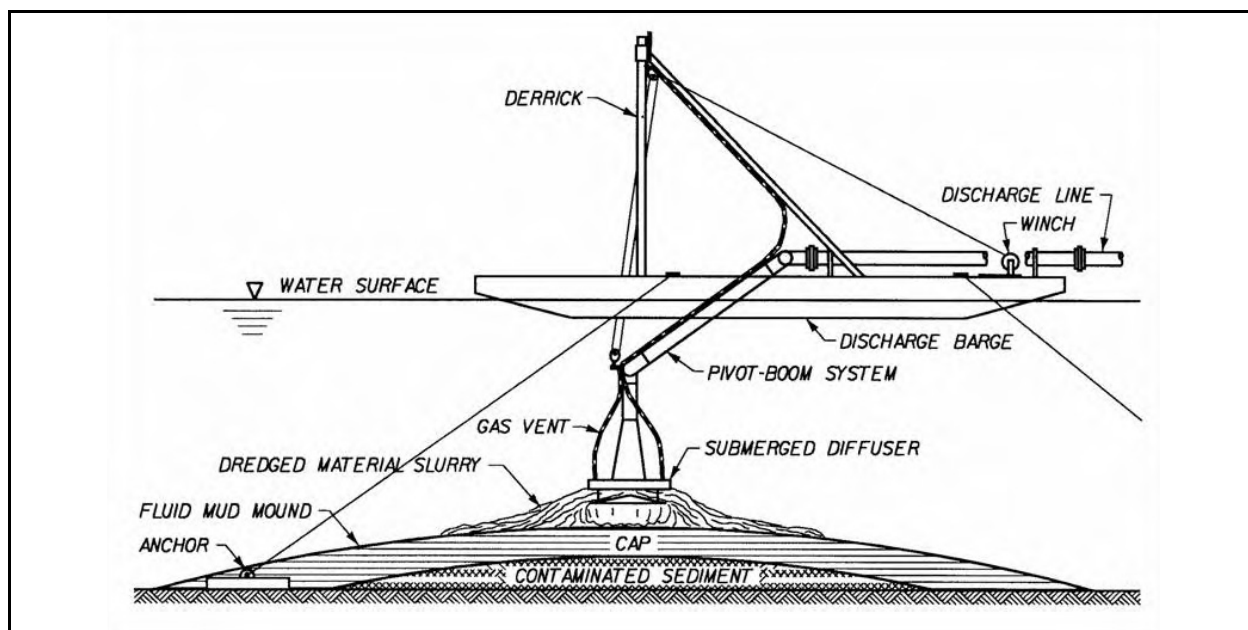


Figure 13. Submerged diffuser system, including the diffuser and discharge barge

the diffuser and pipeline vertically in the water column. By positioning the diffuser several feet above the bottom, the discharge is isolated from the upper water column. The diffuser design allows material to be radially discharged parallel to the bottom at a reduced velocity. By moving the discharge barge, the discharge can be spread to cap larger areas. The diffuser can also be used with any hydraulic pipeline operation including hydraulic pipeline dredges, pump-out from hopper dredges, and reslurried pump-out from barges.

A design for a submerged diffuser system was developed by JBF Corporation as a part of the USACE Dredged Material Research Program (DMRP) (JBF Scientific Corporation 1975; Barnard 1978; Neal et al. 1978). This design consists of a funnel-shaped diffuser oriented vertically at the end of a submerged pipeline section that discharges the slurry radially. The diffuser and pipe section are attached to a pivot boom system on a discharge barge. Design specifications for this submerged diffuser system are available (Neal et al. 1978; Palermo 1994a).



Figure 14. Submerged diffuser

A variation of the DMRP diffuser design was used in an equipment demonstration at Calumet Harbor, Illinois. Although not constructed to the DMRP specifications, this diffuser significantly reduced pipeline exit velocity, confined the discharged material to the lower portion of the water column, and reduced suspended solids in the upper portion of the water column (Hayes et al. 1988). Diffusers constructed using the DMRP design have been used at a habitat creation project in the Chesapeake Bay (Earhart et al. 1988) and at a Superfund pilot dredging project at New Bedford Harbor, Massachusetts, involving subaqueous capping (USACE 1990). At the Chesapeake Bay site, the diffuser was used to effectively achieve dredged material mounding prior to placement of a layer of oyster shell to provide substrate for attachment of oyster spat. At the New Bedford site, the diffuser was used to place contaminated sediment in an excavated subaqueous cell and was effective in reducing sediment resuspension and in controlling placement of contaminated sediment. However, capping operations were started immediately and positioning of the diffuser within 2 ft of the contaminated sediment layer resulted in mixing of cap sediment with contaminated sediment. These results indicate the need for a high degree of control when capping newly placed slurry with a diffuser and the need for adequate time to allow for some self-weight consolidation of slurry material prior to capping. Diffusers have also been successfully used to place and cap contaminated sediments at projects in Rotterdam Harbor in The Netherlands (d'Angremond et al. 1984) and in Antwerp Harbor in Belgium (Van Wijck and Smits 1991).

### **Sand Spreader Barge.**

Specialized equipment for hydraulic spreading of sand for capping has been used by the Japanese (Kikegawa 1983, Sanderson and McKnight 1986). This equipment employs the basic features of a hydraulic dredge with submerged discharge (Figure 15). Material is brought to the spreader by barge, where water is added to slurry the sand. The spreader then pumps the slurried sand through a submerged pipeline. A winch and anchoring system is used to swing the spreader from side to side and forward, thereby capping a large area.

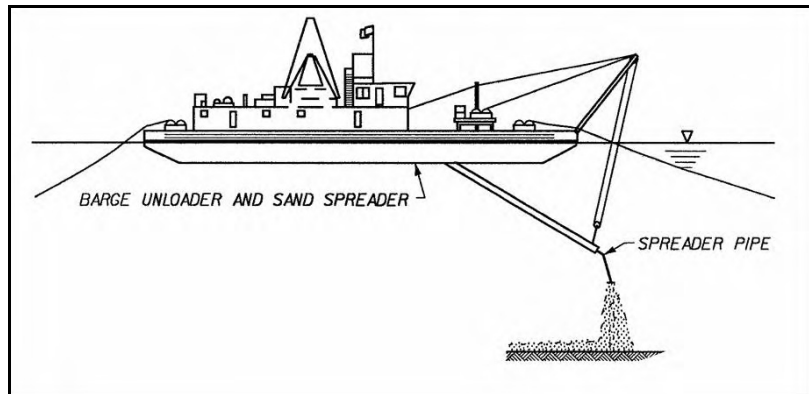


Figure 15. Hydraulic barge unloader and sand spreader barge (from Kikegawa (1983))

**Gravity-fed Downpipe (Tremie).** Tremie equipment can be used for submerged discharge of either mechanically or hydraulically handled granular cap material. The equipment consists of a large-diameter conduit extending vertically from the surface through the water column to some point near or above the bottom. The conduit provides the desired isolation of the discharge from the upper water column and improved placement accuracy. However, because the conduit is a large-diameter straight vertical section, there is little reduction in momentum or impact energy over conventional surface discharge. The weight and rigid nature of the conduit requires a sound structural design and consideration of the forces due to currents and waves.

The Japanese have used tremie technology in the design of specialized conveyor barges for capping operations (Togashi 1983, Sanderson and McKnight 1986). This equipment consists of a tremie conduit

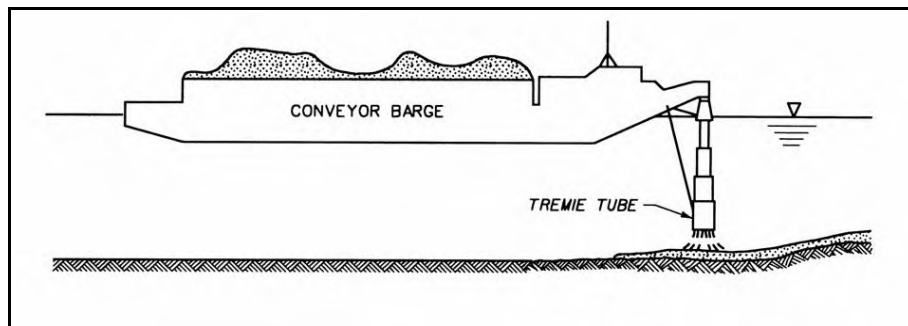


Figure 16. Conveyor unloading barge with tremie (from Togashi (1983))

equipped with a conveyor (Figure 16). The material is initially placed in the barge mechanically. The conveyor then mechanically feeds the material to the tremie conduit. A telescoping feature of the tremie allows placement at depths of up to approximately 40 ft. Anchor and winch systems are used to swing the barge from side to side and forward so that larger areas can be capped, similar to the sand spreader barge.

A variation on the tremie system was used at the ISC demonstration in Hamilton Harbor, Lake Ontario (Zeman and Patterson 1996a, 1996b). Sand, piled on a flat-deck barge, was placed into a hopper using a small front-end loader. Inside the hopper, the sand was slurried and routed into a number of 6-in.-diam, PVC plastic tubes (Figure 17). The tubes extended 30 ft down, where the sand exited about 5-10 ft above the sediment. An anchor-and-winch system was used to position the barge.



Figure 17. Tremie system employed at Hamilton Harbor, Lake Ontario

**Hopper Dredge Pump-down.** Some hopper dredges have pump-out capability by which material from the hoppers is discharged like a conventional hydraulic pipeline dredge. In addition, some have further modifications that allow pumps to be reversed so that material is pumped down through the dredge's extended dragarms. Because of the expansion at the draghead, the result is similar to using a diffuser section. Pump-out depth is limited, however, to the maximum dredging depth, typically about 60-70 ft.

**EQUIPMENT AND PLACEMENT TECHNIQUES FOR ARMORING LAYERS:** Placing armor layers on caps can apply techniques commonly used for purposes of streambank and shoreline erosion protection. The Sheboygan River ISC was constructed using stone (1- to 2-in. cobbles) for erosion protection (Eleder 1992). Armor stone was also used at the GM Massena site.<sup>1</sup> Although there is very little experience with armor stone at capping applications, guidance from

<sup>1</sup> Personal Communication. 1997. Mr. E. Thomas Kenna, Environmental Engineer, U.S. Army Engineer District, Buffalo, NY.



streambank and shoreline erosion protection (USACE 1990, 1994) may be applicable to some capping sites.

Methods that have been used for placing armor stone include placing by hand; machine placing, such as from some form of bucket; and dumping from trucks and spreading by bulldozer. Cobbles were placed at the Sheboygan River ISC by bucket from a land-based crane with support from workers wading in the shallow river (Figure 18). Gravel-sized armor stone was placed onto the cap at Massena using a backhoe, which was emptied a few feet above the cap.



Figure 18. Stone placement at Sheboygan River

Where gravel, cobbles, or small stone must be placed in deeper water, it may be possible to push them over the side of a flat deck barge or down a modified tremie. Potential effects with such methods that should be considered include the disruption or penetration of other cap components by the armor stone impact and the differential settling of graded stone. In order to reduce the force of impact, it may be necessary to handle the stone by bucket and release it closer to the cap surface or pass the material down some type of slide towed behind the barge.

Because of the uncertainties associated with underwater placement of stone, the design thickness of the erosion component should be increased by 50 percent.

**CAPPING WITH FINE-GRAINED MATERIALS:** Coarse-grained material is generally preferred for capping because it is less likely to erode, provides less dispersion in the water column, and requires less time to consolidate. However, clean fine-grained material may also be appropriate cap material where erosion is not a concern. Fine-grained sediment is frequently available from maintenance dredging activities. Fines usually exhibit lower permeability with improved retention of contaminants.

Most equipment used for coarse-grained material placement can also be used to place fine-grained material with special considerations. Submerged discharge is generally desired for hydraulic placement of fine-grained material for increased placement accuracy and reduction of material losses and contamination. Plans are underway to use clean fine-grained material from San Juan Harbor to cap similar contaminated material from the harbor placed in a CAD (Bailey et al. 2003). Fine material can also be used in conjunction with coarse material using a “sandwich method” to promote consolidation (Tan et al. 2003).

**PLACEMENT OF GEOSYNTHETIC FABRICS AND MEMBRANES AND GEOSYNTHETIC FABRIC CONTAINERS (GFCs):** Placing geosynthetic fabrics between soft sediment and a sand cap may allow sand capping of sediments otherwise too soft to support



a cap. The geosynthetics allow the sediments to consolidate and gain strength under the sand cap load (Palermo et al. 1998b, Appendix C).

Experience with placement of geosynthetic fabrics in subaqueous conditions is limited. At the Chicago Area Confined Disposal Facility (CDF), a plastic liner was pulled from a workbarge in sections that were heat-welded together on the barge surface (Savage 1986). A membrane measuring 110 ft by 240 ft was placed as a temporary subaqueous cap at Manistique River by crane from a workbarge and anchored using concrete blocks (Palermo et al. 2002). This operation required some manipulation of the cover by divers. A geotextile cap was deployed using a reel at Eitheim Bay in Norway (Instanes 1994). Geosynthetic fabric was also used at Sheboygan, comprising two layers of the armoring (Eleder 1992). Geotextile sheets, 30 m by 51 m with a 1-m overlay, were placed over mercury-contaminated soft sediments at the Minimata site in Japan, before being covered with several layers of sand (Palermo et al. 1998b). Geosynthetics were also utilized at another sand capping project in Soerfjord, Norway in which the geotextile consists of a composite material of nonwoven geomembrane and woven polyester geotextile that is denser than water (Instanes 1994). Fourteen sheets were placed with an overlay of 2.5 m before being capped with 30-60 cm of sand. At the Mocks Pond, Indiana site, a polyester geotextile was installed in five overlapping sections, anchored to the shoreline (Thompson et al. 2003a). The highly permeable material exhibits a density that sinks when saturated, allowing ease of installation and release of gas buildup.

Geosynthetics have been fabricated with anchors around the perimeter and other locations to simplify aquatic deployment. In most cases, placing geosynthetic fabrics at a capping site will require the coordinated actions of several crews and vessels. The material will have to be anchored quickly, especially where currents, waves, or tidal conditions are subject to rapid changes.

Geosynthetic fabric containers (GFCs) are bags or tubes made from geosynthetic fabric that can be filled with contaminated dredged material. The GFC acts as a filter cloth, allowing the water to escape but retaining almost all of the fine (silt and clay) particles. GFCs can be manufactured to line barges. Contaminated dredged material is placed in the GFCs (either mechanically or hydraulically), which are then sewn shut prior to placing the GFC from split-hull barges at the disposal site. Cranes have also been used to place geotubes prior to filling, directly lifting folded fabric tubes from working barges. Longer tubes have been deployed from large reels mounted on barges. Containing contaminated sediments in GFCs offers the potential to eliminate the wide, thin apron normally associated with conventional bottom dumping of fine-grained sediments, thus substantially reducing the volume of cap material required and reducing the potential for contaminated sediments to extend beyond the site boundary. GFCs also have the potential to eliminate water quality problems at the disposal site by essentially eliminating loss of fine sediment particulates and associated contaminants to the water column.

GFCs have been used on at least two USACE projects. The first was construction of training dikes in the lower Mississippi River (Duarte et al. 1995), and the second was placement of sandy sediment with heavy metal contaminants in a CAD site in Los Angeles Harbor (Mesa 1995). At present, GFCs are much more expensive than conventional bottom placement due to costs of materials, increased dredge cycle times, and increased labor requirements associated with

installing the GFCs in the barge, and possible reductions in dredge production rate. Considerable engineering problems are also associated with successfully deploying the GFCs without having them rupture. The decision to use GFCs for a capping project should be made based on the benefits versus costs rather than a blanket decision based solely on the desire to reduce losses to the water column. Data collected from a 1996 demonstration of GFCs conducted jointly by the New York District and the Port of New York and New Jersey should provide additional data on GFC viability. However, additional research is needed to better define GFC abilities to reduce water column losses of contaminants and to refine engineering aspects associated with deployment. Clausner et al. (1996) summarize the present state of the art on using GFCs with contaminated sediments.

**PLACEMENT OF ALTERNATIVE CAPPING MATERIALS:** Some alternative innovative cap materials are being developed to address specific contaminant issues. One such material, AquaBlok™, consists of a gravel/rock core covered by a layer of clay mixed with polymers that expands in water, decreasing its permeability (Hull et al. 1999). Other potential innovative cap materials include zero-valent iron, apatite (phosphate mineral), BioSoil™ (high organic content from composting to encourage degradation of organic contaminants), OrganoClay sorbents, Ambersorb sorbent, and coal-based sorbents. Some “active capping” technologies are being evaluated via a demonstration project on the Anacostia River (Hazardous Substance Research Center/South and Southwest Research (HSRC/S&SW) 2002).

A demonstration project on the Ottawa River conducted by the City of Toledo provided field-scale testing of AquaBlok™. Various installation techniques were evaluated, including the use of a telescoping articulated conveyor (both shore- and barge-mounted), helicopter and dragline delivery systems to apply the dry material (Hull and Stephens 2000). Another project at Eagle River Flats, Fort Richardson, Alaska demonstrated application of AquaBlok™ using PVC bulk drop bags loaded with 2500-kg AquaBlok™, rigged to a Blackhawk helicopter (Pochop et al. 2000).

Furthermore, a capping pilot study on the Grasse River, Massena, New York, evaluated several means of applying various cap materials including a sand/topsoil mixture, granular bentonite, a sand/soil/bentonite slurry, and AquaBlock™. Application techniques included surface and subsurface installation using a crane-mounted clamshell, subsurface placement via tremie, and a pneumatic broadcasting technique to apply the granular bentonite material. The optimal results for this particular project were achieved with the 1:1 sand/topsoil material placed via clamshell either at the water surface or subsurface (Alcoa 2003).

**SUMMARY:** A number of different equipment types and placement techniques can be considered for capping operations. Conventional discharge of mechanically dredged material from barges and hydraulically dredged material from hopper dredges or pipelines can be considered if the anticipated bottom spread and water column dispersion are acceptable. If water column dispersion must be reduced or if additional control in placement is required, use of diffusers, tremies, or other equipment for submerged discharge can be considered. Controlled discharge and movement of barges and use of spreader plates or boxes with hydraulic pipelines can be considered for spreading a capping layer over a larger area. Compatibility between equipment and placement technique for contaminated and capping material and accuracy and

control of the equipment during placement are essential for any capping operation. Contaminated sediment capping projects are summarized on the web at <http://www.hsrb.org/hsrb/html/ssw/capsummary.pdf>.

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